Effect of an initial solution in iterative reconstruction of dynamically changing objects

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Abstract

Visualizing and analyzing dynamic processes in 3D is an emerging topic, e.g. in geosciences (Berg *et al.*, 2009; Cnudde and Boone, 2013; Bultreys *et al.*, accepted), which has only recently become possible due to fast, high-resolution CT scanning. However; dynamically changing objects pose a challenge in CT-imaging because the existing reconstruction algorithms, which reconstruct the sample volume from a number of scan images, presume an unchanging sample during the acquisition of the projection images. Movements or changes during the scan cause artefacts in the resulting volume. Furthermore, when fast processes are visualized, the acquisition time needs to be reduced, thus drastically decreasing the signal-to-noise ratio (SNR).

To address these issues, an iterative reconstruction technique is applied, where an initial solution is provided to the algorithm. In this work, we present an evaluation of this method based on both simulations and real experimental data.

Introduction

The simultaneous Algebraic Reconstruction Technique (SART) is an iterative algorithm to reconstruct volumes from CT-scans (Beister *et al*. 2012). A (typically empty) volume is initiated and improved by back-projecting the difference between a simulated projection of this (empty) initial solution and the measured projection at the same viewing angle. This is done for every measured projection. The resulting volume is then used in the next iteration step, where the projection/back projection process is repeated using the intermediate solution. After a number of iterations, the solution converges to a final reconstructed volume.

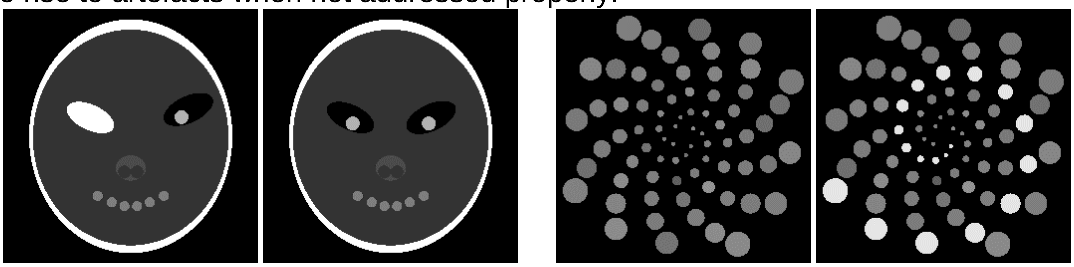
Instead of an empty volume, an initial solution can be used in the first step. This can be the reconstruction of an earlier scan of the same object or another volume resembling the one that’s being reconstructed. An initial solution may improve the convergence speed and the quality of the resulting reconstruction (Brabant 2013).

An initial solution can reduce the number of projections needed to get the same quality of reconstruction. In this way a scan for one reconstruction needs less time. To a lesser extend, an initial solution can also cope with more noise than the conventional SART-reconstruction, starting from an empty volume. Therefore, less time is needed per projection and the total scanning time decreases.

A reconstruction algorithm can be further improved if it is known which regions in the initial solution are most likely to undergo changes. These regions recieve a higher weight during the back projection process. The number of projections needed can thus be further reduced. Using only a small number of projections, even partial CT-scans can be reconstructed at an improved quality.

Methods

The SART-reconstruction using an initial solution is compared with the conventional SART-reconstruction using an empty volume as initial solution for a number of parameter values. Specifically, the projection angle, the relaxation factor, the number of projections, the number of iterations and the amount of simulated noise are varied. Most work is performed using phantom data, where a slightly modified version of the ideal solution one is used as the initial solution (Fig. 1). Because these are phantoms, the reconstruction can be compared with a ground truth to quantitatively evaluate the reconstruction. Two effects are investigated: when the initial phantom has a part that has a different attenuation coefficient and when it has a part that has moved. Both effects give rise to artefacts when not addressed properly.



(a) **(b)** **(c)** **(d)**

Fig. 1. *Two phantoms. (a) and (c) are the initial solutions, (b) and (d) the ideal solutions*

An example of a dynamic process is fluid flow through porous media such as geomaterials. This dynamic process will be used to test the reconstruction with an initial solution on a real-life example. Images of this are shown in figure 2.

A high-quality scan of the dry sample is acquired before the dynamic process is initiated. This scan is reconstructed with conventional SART. The result is used as an initial solution for the scans acquired during the process. The fluid presumably follows the pores in this rock, further limiting the regions where the reconstruction can differ from the initial solution. Again, the result is compared with conventional SART to evaluate whether the initial solution is an improvement.

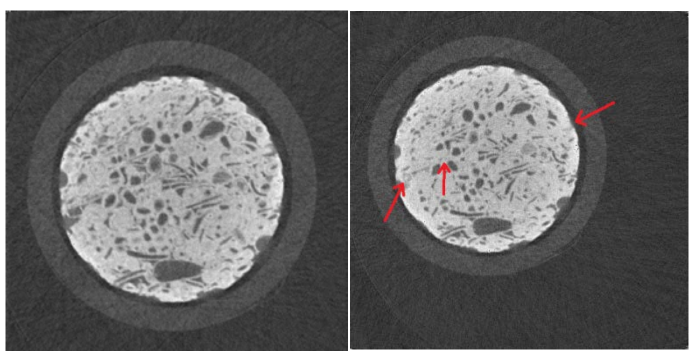


Fig. 2. *The scanned geomaterial. To the left is the situation before the dynamic process was initiated; this is used as the initial solution. To the right is the situation after fluid flow, which is being reconstructed. The major differences are indicated with arrows.*

Both methods, a phantom and the scanning of fluid flow through porous media, are used to test the extented algorithm, in which an initial solution is backed up with different weighting in the back projection process for different regions of the volume. The weightings are based on the grey values of the initial solution: for the geomaterial heigher weightings are assigned to the attenuation coefficient of air. These are the pores where the fluid will most likely flow. These reconstructions are compared with conventional SART and with the naive implementation of an initial solution. The effect of the number of projections and of the signal to noise ratio is investigated by variing them.

Results

Movement artefacts occur when the relaxation factor, the projection angle, the number of projections or the number of iterations is too low. Noise can obscure the artefacts if it is strong enough, as can be seen in figure 3.

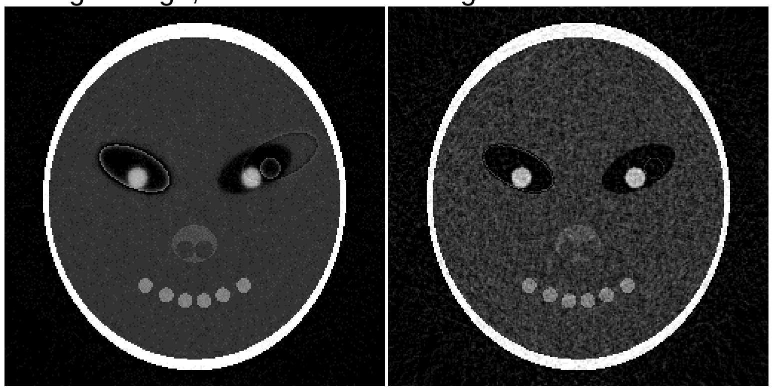


Fig. 3. *Reconstructions with initial solution for different amounts of the simulated noise.*

The initial solution yields an improvement when compared with conventional SART. The same reconstruction quality can be achieved for a lower number of projections, both in phantom and in real data. Therefore an initial solution can help reconstruct a dynamically changing sample.

This effect becomes even larger when combining an initial solution with variable weighting. A good reconstruction can be obtained with a very low number of projections, as demonstrated in figure 4.

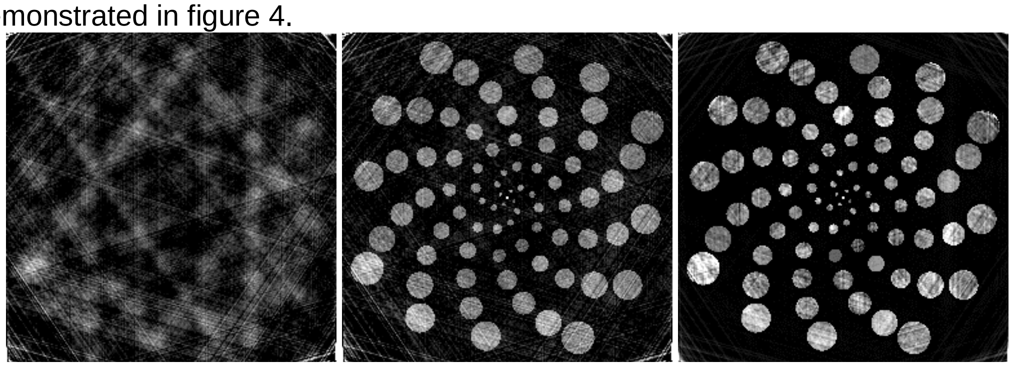


Fig. 4. *At the left a conventional SART-reconstruction. In the middle a reconstruction with an initial solution and at the right one with the use of weightings. 6 projections were used.*

A necessary condition to get good results with weighted reconstruction is a correct choice of the weighting volume. Giving a low weight to regions were change is present results in reconstructions worse than the ones with a naive implementation of the initial solution and in some cases even worse than the conventional SART-reconstruction.

A disadvantage of using a weighted reconstruction is the relative contribution of noise. The noise is now primarily backprojected in the relatively small volume with large weightings, augmenting its importance. This is especially important because these regions with high weights are where the initial solution differs from the reconstructed volume and where the dynamic process takes place. The negative effect of noise on the quality of the reconstruction increases fast with the number of iterations and projections.

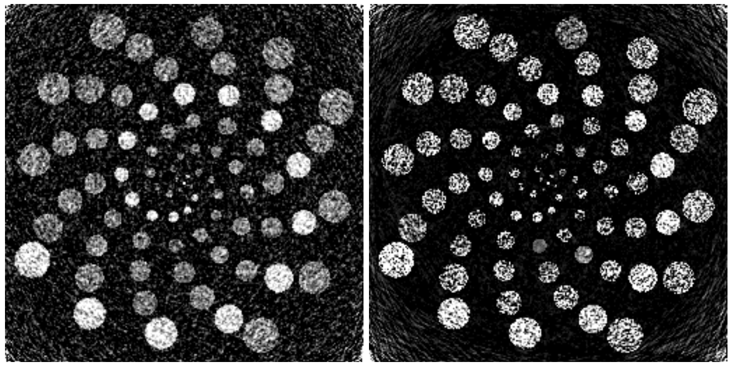


Fig. 5. *Left is a reconstruction with an initial solution and at the right one with the use of weightings. 300 projections were used.*

An example of the effect of noise on the reconstruction with both an initial solution and a weighted algorithm is shown in figure 5. Especially the smaller regions in the center suffer from noise in the weighted algorithm.

The reconstructions of the geomaterial need less projections when using an initial solution, compared to the conventional SART. A reconstruction with correct weights pushes this number down even more. This can be seen in figure 6.

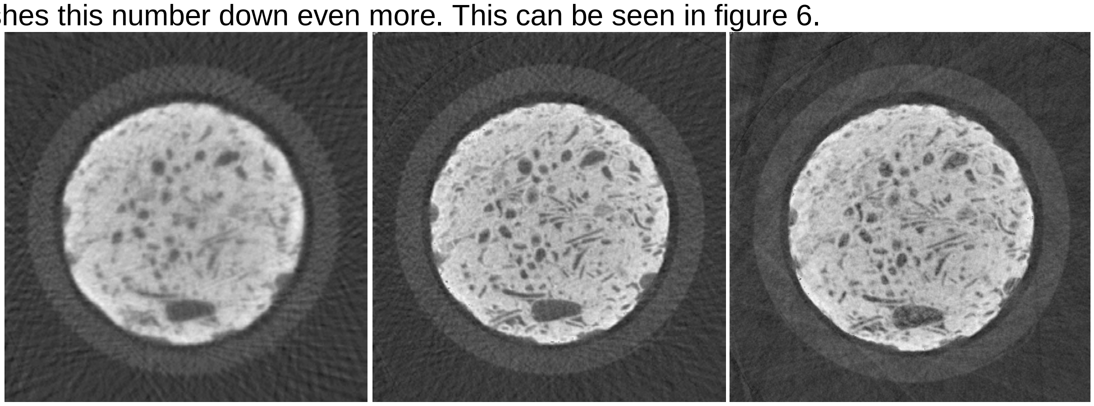


Fig. 6. *At the left a conventional SART-reconstruction. In the middle a reconstruction with an initial solution. Both used 100 projections. At the right a reconstruction with weights, using 15 projections.*

Conclusion

An initial solution, potentially with a weighting volume, can greatly improve the quality of a reconstruction with a low number of projections.

This can be benificial in reconstructing dynamic processes, provided a detailed scan before or after the process is taken to serve as the initial solution. The weights, if used, should correctly represent the changing volume. A wrong weighting volume reduces the reconstruction quality instead of improving it.

While a naive implementation of an initial volume can reduce the scanning time both by reducing the number of projections and reducing the time per projection (increasing the noise), the adding of a weighting volume only reduces the number of projections needed, since noise has an increased effect on this reconstruction. The number of projections may, however, be lowered to a great extend. In this way the scanning time gets reduced further than with an initial solution alone.

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References

Beister M., Kolditz D. and Kalender W. A. (2012). Iterative reconstruction methods in X-ray CT ***Physica Medica 28***, 94-108.

Berg S., Ott H., Klapp S.A., Schwing A., Neiteler R., Brussee N., Makurat A., Leu L., Enzmann F., Schwarz J.-O. (2013). Real-time 3D imaging of Haines jumps in porous media flow. **Proceedings of the National Academy of Sciences 110(10),** 3755-3759.

Brabant L. (2013). *Latest developments in the improvement and quantification of high resolution X-ray tomography data*. UGent, Belgium, http://hdl.handle.net/1854/LU-4193900

Bultreys T., Boone M.A., Boone M.N., De Schryver T., Masschaele B., Van Hoorebeke L. and Cnudde V. (accepted for publication). Fast laboratory-based micro-computed tomography for pore-scale research: illustrative experiments and perspectives on the future. **Advances in Water Resources**

Cnudde V. and Boone M.N. (2013). High-resolution X-ray computed tomography in geosciences: A review of the current technology and applications. **Earth-Science Reviews 123**, 1-17